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TECHNICAL NOTE

No. 1169

THE EFFECT OF GEOMETRIC DIHEDRAL ON THE AERODYNAMIC CHARACTERISTICS OF A 40° SWEPT-BACK WING OF ASPECT RATIO 3

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THE EFFECT OF GEOMETRIC DIHEDRAL ON THE AERODYNAMIC CHARACTERISTICS OF A 40° SWEPT-BACK WING OF ASPECT RATIO 3

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SUMMARY

Force tests at low Reynolds numbers were made to determine the effect of changes in the geometric dihedral on the aerodynamic characteristics of a wing of aspect ratio 3 having an angle of sweepback of 40° measured at the quarter-chord line. The results of the tests for the swept-back wing of aspect ratio 3 indicated that, for low and moderate lift coefficients, changes in geometric dihedral from -10° to 10° resulted in a change in the effective dihedral that was about 75 percent as great as that obtained for an unswept wing of aspect ratio 6. For dihedral angles outside the range of -10° to 10°, changes in geometric dihedral produced about half as much change in effective dihedral as for dihedral angles between -10° and 10°. At a lift coefficient above a value of 0.8, the maximum values of effective dihedral obtained with large negative geometric dihedral angles were greater than those obtained with 0° geometric dihedral. Over the linear range of the lift curve, the directional-stability parameter generally increased with increasing negative dihedral and increasing lift coefficient, but did not change appreciably with increasing positive dihedral. Increasing positive dihedral resulted in an increase in the nosing-up pitching moments (destabilizing) at the stall, and increasing negative dihedral resulted in an increase in nosing-down moments (stabilizing) at the stall. Increasing positive or negative dihedral caused a decrease in the lift-curve slope and an increase in the variation of lateral force with sideslip.

INTRODUCTION

One undesirable characteristic of highly swept-back wings is the large variation in effective dihedral with a variation in lift coefficient. This variation tends to give excessive values of effective dihedral at moderate and high lift coefficients. In order to limit the maximum value of effective dihedral to a value that will permit attainment of satisfactory dynamic lateral stability and control characteristics, it may be necessary in many cases to use negative geometric dihedral. In order to obtain some indication of the effects of changes in geometric dihedral on the aerodynamic characteristics of a swept-back wing, an investigation has been made at low Reynolds numbers in the Langley free-flight tunnel. This investigation consisted in force tests of a 40° swept-back wing of aspect ratio 3 with geometric dihedral angles ranging from 20° to -30°. The results of the investigation are presented herein.

SYMBOLS

The forces and moments were measured with respect to the stability axes. (See fig. 1.)

C_L lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{M}{qS\bar{c}}\right)$

C_l rolling-moment coefficient $\left(\frac{L}{qSb}\right)$

C_n yawing-moment coefficient $\left(\frac{N}{qSb}\right)$

C_Y lateral-force coefficient $\left(\frac{\text{Lateral force}}{qS}\right)$

L rolling moment about X axis, foot-pounds

M pitching moment about Y axis, foot-pounds

N	yawing moment about Z axis, foot-pounds
S	wing area (0° dihedral wing), square feet
b	wing span (0° dihedral wing), feet
c	wing chord, measured in plane parallel to plane of symmetry, feet
$\bar{c}$	wing mean aerodynamic chord measured in plane parallel to plane of symmetry, feet
y	lateral location of wing mean aerodynamic chord measured from axis of symmetry, inches
z	vertical location of wing mean aerodynamic chord measured from lower surface of the wing (0° dihedral), inches
A	wing aspect ratio $\left(\frac{b^2}{S}\right)$
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
ρ	mass density of air, slugs per cubic foot
V	airspeed, feet per second
ϕ	angle of roll, degrees
β	angle of sideslip, degrees
ψ	angle of yaw ($-\beta$), degrees
Γ	geometric dihedral angle, measured with respect to under-surface of wing, degrees
α	angle of attack at the lower surface of the wing, degrees
λ	taper ratio, ratio of tip chord to root chord
C_{l_β}	effective-dihedral parameter, rate of change of rolling-moment coefficient with angle of sideslip, per degree $\left(\frac{\partial C_l}{\partial \beta}\right)$
C_{n_β}	directional-stability parameter, rate of change of yawing-moment coefficient with angle of sideslip, per degree $\left(\frac{\partial C_n}{\partial \beta}\right)$

C_{Y_β} lateral-force parameter, rate of change of lateral-force coefficient with angle of sideslip, per degree $\left(\frac{\partial C_Y}{\partial \beta}\right)$

$\frac{\partial C_{l_\beta}}{\partial \Gamma}$ rate of change of effective-dihedral parameter with geometric-dihedral angle, per degree

C_{L_α} lift-curve slope, per degree $\left(\frac{\partial C_L}{\partial \alpha}\right)$

APPARATUS AND TESTS

The force tests to determine the aerodynamic characteristics of the various wing configurations were made on the Langley free-flight-tunnel six-component balance which rotates in yaw with the model so that all forces and moments are measured with respect to the stability axes. (See fig. 1.) A complete description of the balance system is given in reference 1. All the tests were run at a dynamic pressure of 3.0 pounds per square foot corresponding to a test Reynolds number of 249,000 based on a mean aerodynamic chord of 0.778 feet.

A sketch of the tapered wing ($\lambda = 0.5$) of aspect ratio 3, with a sweepback of 40° measured at the quarter-chord line, is presented in figure 2. The wing has a Rhode St. Genese 33 airfoil section parallel to the plane of symmetry. This wing section was used in accordance with the free-flight-tunnel practice of using airfoil sections that obtain maximum lift coefficients in the low-scale tests more nearly equal to those of full-scale wings. The wing was constructed of pine in three sections: a 0.10b center panel, and two 0.45b outboard panels. The outboard panels were hinged to the center panel and faired wedge blocks were used to give a range of geometric dihedral angles from 20° to -30° measured at the under surface of the panels perpendicular to the plane of symmetry.

A series of force tests were made for dihedral angles of 0°, ±5°, ±10°, ±20°, and -30° to determine the aerodynamic characteristics of the wing over the lift-coefficient range for yaw angles of 0° and ±5°. A few force tests were made over a range of yaw angles of 30° to -30° at an angle of attack of 2° to determine whether the values of the lateral-stability parameters obtained from angle-of-attack tests at ±5° yaw were reliable over a reasonable yaw-angle range.

RESULTS AND DISCUSSION

All the test data are based on the area, span, and mean aerodynamic chord of the zero-dihedral configuration and are measured with respect to the same moment-reference axes unless otherwise stated. The origin of the moment-reference axes shown in figure 2 is the quarter-chord point of the mean aerodynamic chord when the wing is set at 0° geometric dihedral. Since the mean aerodynamic chord moves upward with respect to the moment-reference point as positive dihedral is increased and downward as negative dihedral is increased, it is necessary to correct the basic data presented with respect to the moment-reference axes when moment data are desired about some point on the mean aerodynamic chord of the wing.

The results of the angle-of-attack tests at angles of yaw of 0° and ±5° are presented in figure 3. The results of the yaw tests at $\alpha = 2^\circ$ are presented in figure 4. A comparison of the data of figure 3 with data of figure 4 indicates that at least over the linear range of the lift curve, the lateral-force parameter C_{Y_β}, the directional-stability parameter C_{n_β}, and the effective-dihedral parameter C_{l_β} obtained from the tests at yaw angles of ±5° give reliable values of these parameters over a range of yaw angles of approximately ±15°.

The longitudinal-stability characteristics of the wing over the dihedral range have been summarized in figure 5 and the lateral-stability characteristics in figures 6 to 8. Symbols, which have been used in some of the summary plots to aid in distinguishing the curves, should not be taken as test points.

Lift Characteristics

The data of figure 5 indicate that the lift-curve slope decreases with increasing positive or negative geometric dihedral. The investigation of reference 2 showed that the decrease in lift-curve slope with geometric dihedral can be expressed as

$$C_{L_{\alpha_\Gamma}} = \left(C_{L_\alpha}\right)_{\Gamma=0^\circ} \cos^2\Gamma \tag{1}$$

This theoretical relationship is presented in figure 5 and is in good agreement with the experimental results.

The low-scale lift data in figure 3 indicate that the maximum lift coefficient generally decreased with increasing positive or negative geometric dihedral. This decrease in maximum lift coefficients resulted from the fact that the lift coefficients were based on the area of the wing with zero dihedral and not the projected wing area, which decreased with dihedral.

The data of figure 3 also show an increase in the angle of attack of maximum lift with increasing positive and negative geometric dihedrals. As pointed out in reference 2, this increase is caused by a reduction in the angle of attack measured in the plane normal to the wing surface as the geometric dihedral is increased either in the positive or negative direction.

Pitching-Moment Characteristics

The data of figure 5 indicate that, when the pitching moments are referred to the moment-reference axes, an apparent increase in longitudinal stability dC_m/dC_L with increasing geometric dihedral results. When the pitching moments are referred to the mean aerodynamic chord for each dihedral angle, however, only a slight change in longitudinal stability with geometric dihedral results.

The pitching-moment data of figure 3 indicate that geometric dihedral affected the low-scale pitching-moment characteristics at high lift coefficients. These data obtained at low Reynolds number indicated that increasing positive geometric dihedral resulted in an increase in nosing-up pitching moments (destabilizing) at the stall and increasing negative dihedral resulted in an increase in nosing-down moments (stabilizing) at the stall. The changes in pitching moment at stall are not so pronounced when these data are corrected to the mean aerodynamic chord for the corresponding dihedral configuration.

Rolling-Moment Characteristics (Effective Dihedral)

The data of figure 6 indicate that up to a lift coefficient of 0.80 the effective-dihedral parameter $-C_{l_\beta}$ increases with lift coefficient and positive geometric dihedral and decreases with negative geometric dihedral. The wing with 0° geometric dihedral reaches a maximum value of $-C_{l_\beta}$ at a lift coefficient of 1.0. With increasing positive geometric dihedral the maximum value of $-C_{l_\beta}$ occurs at increasingly lower lift coefficients (0.90 for 20° dihedral). With negative geometric dihedral, maximum values of $-C_{l_\beta}$ would be reached at some lift coefficient beyond maximum lift. This phenomena can be explained by the fact that the change in C_{l_β} with lift coefficient near maximum lift is governed by the nature of the wing stall. With positive geometric dihedral the angle of attack resulting from sideslip is such as to increase the angle of attack on the leading-wing panel and to decrease the angle of attack on the trailing-wing panel. With negative geometric dihedral the opposite effect takes place and the leading-wing panel has the smaller angle of attack. As maximum lift is approached in a sideslip, the wing panel with the higher angle of attack therefore begins to stall first and a decrease in lift (and rolling moment) produced by that panel results.

The data of figure 7, which is a cross plot of figure 6, indicate that, for any lift coefficient in the linear portion of the lift curve, an approximately linear variation of effective-dihedral parameter C_{l_β} with geometric dihedral occurs for a range of geometric dihedrals from -10° to 10°. The variation of C_{l_β} with dihedral $\frac{\partial C_{l_\beta}}{\partial \Gamma}$ decreases for geometric dihedral angles outside the range of -10° to 10°. The curves of figure 7 are cross-plotted in figure 8, which shows that the dihedral effectiveness parameter $\frac{\partial C_{l_\beta}}{\partial \Gamma}$ for geometric dihedral angles between -10° and 10° varies over the lift range from about -0.00017 to -0.00012 and is more than twice the value of $\frac{\partial C_{l_\beta}}{\partial \Gamma}$ for geometric dihedrals in the range outside ±10°. For an unswept wing of aspect ratio 6, which is representative of wings on many present-day conventional airplanes, the value of $-\frac{\partial C_{l_\beta}}{\partial \Gamma}$ is 0.00021 (reference 3). The average value of $-\frac{\partial C_{l_\beta}}{\partial \Gamma}$ over the low and moderate lift-coefficient range for dihedral angles between ±10° for the wing tested was 0.00016 or about 75 percent of the value for the unswept wing of aspect ratio 6. This reduction in the value of $\frac{\partial C_{l_\beta}}{\partial \Gamma}$ for the swept-back wing as compared to the unswept wing is attributed in part to the lower lift-curve slope of the swept-back wing.

The data of figures 6 and 7 indicate that at any lift coefficient up to a lift coefficient of 0.8, increasing the negative geometric dihedral causes a reduction in the value of $-C_{l_\beta}$. At a lift coefficient above 0.8, however, increasing the negative geometric dihedral increases the value of $-C_{l_\beta}$. For example, for lift coefficients above 1.0, the values of $-C_{l_\beta}$ are greater for geometric dihedral angles of -20° and -30° than for zero geometric dihedral.

Yawing Moment and Lateral Force

The cross-plots of figures 6 and 7 indicate that the directional-stability parameter C_{n_β} generally increases with increasing negative dihedral and increasing lift coefficient over the linear range of the lift curve but is not appreciably affected by increasing positive dihedral. An analysis of the forces acting on the wing indicated that at any lift coefficient in the linear range of the lift curve the directional-stability parameter C_{n_β} should increase with an increase in negative dihedral and decrease with an increase in positive dihedral. The discrepancy between the analysis and the test data for wings with positive dihedral has not been explained. The data of figures 6 and 7 also indicate that, over the linear portion of the lift curve, the variation of lateral force with sideslip C_{Y_β} increases with increasing positive or negative dihedral but does not vary with lift coefficient.

CONCLUDING REMARKS

The effects of varying the dihedral angle of a wing of aspect ratio 3 having an angle of sweepback of 40° measured at the quarter-chord line were determined by force tests made at low Reynolds numbers and the results are summarized as follows:

1. For low and moderate lift coefficients changes in geometric dihedral from -10° to 10° resulted in an effective dihedral change approximately 75 percent as great as that obtained for an unswept wing of aspect ratio 6. For dihedral angles outside the range between -10° to 10°, changes in geometric dihedral produced only about half as much change in effective dihedral as for dihedral between 10° and -10°. At lift coefficients above 0.8, the maximum values of effective dihedral for wings with large negative dihedral angles were greater than the maximum value obtained for wings with 0° geometric dihedral.

2. Over the linear range of the lift curve, the directional-stability parameter generally increased with increasing negative dihedral and increasing lift coefficient but showed no appreciable change with increasing positive dihedral.

3. Increasing positive dihedral resulted in increasing nosing-up pitching moments (destabilizing) at the stall and increasing negative dihedral resulted in increasing nosing-down moments (stabilizing) at the stall.

4. Increasing positive or negative dihedral resulted in a decrease in the lift-curve slope and an increase in the variation of lateral force with sideslip.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., September 19, 1946

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2. Purser, Paul E., and Campbell, John P.: Experimental Verification of a Simplified Vee-Tail Theory and Analysis of Available Data on Complete Models with Vee Tails. NACA ACR No. L5A03, 1945.

3. Shortal, Joseph A.: Effect of Tip Shape and Dihedral on Lateral-Stability Characteristics. NACA Rep. No. 548, 1935.

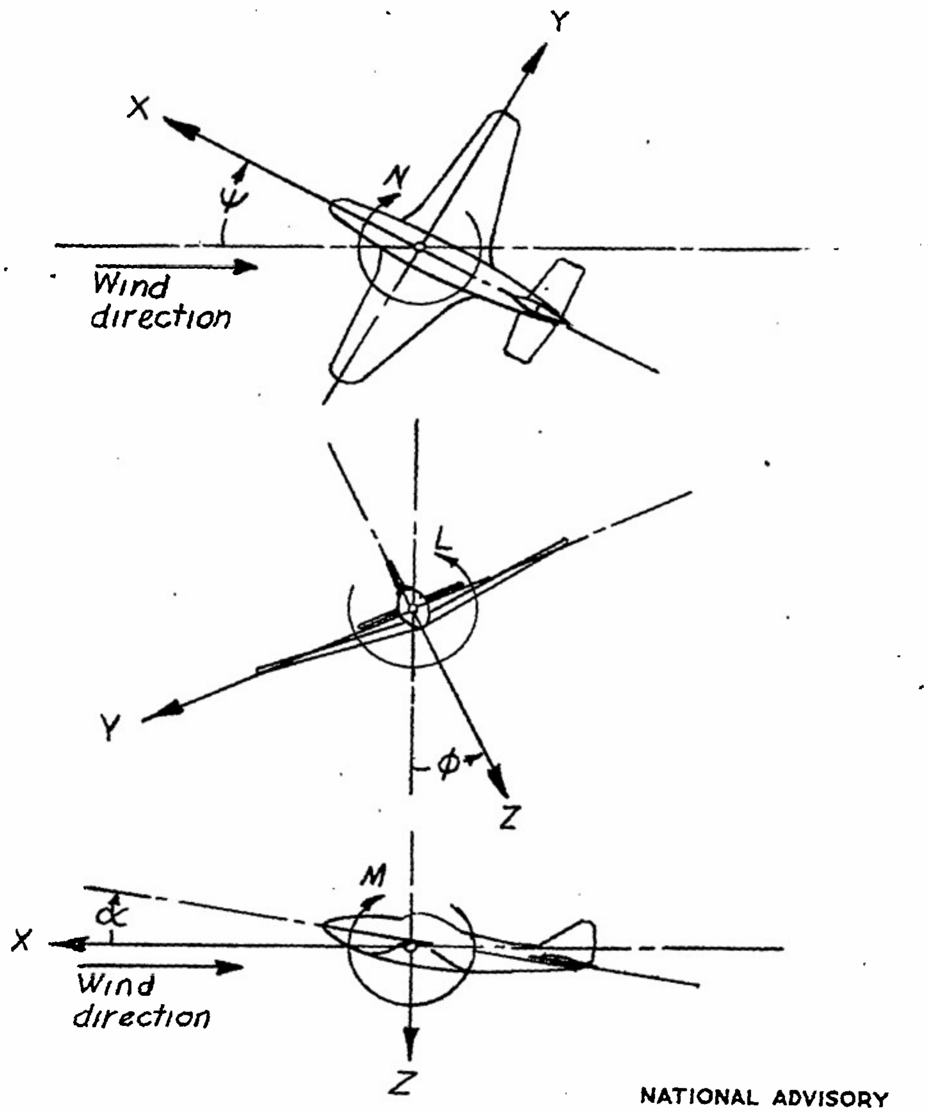
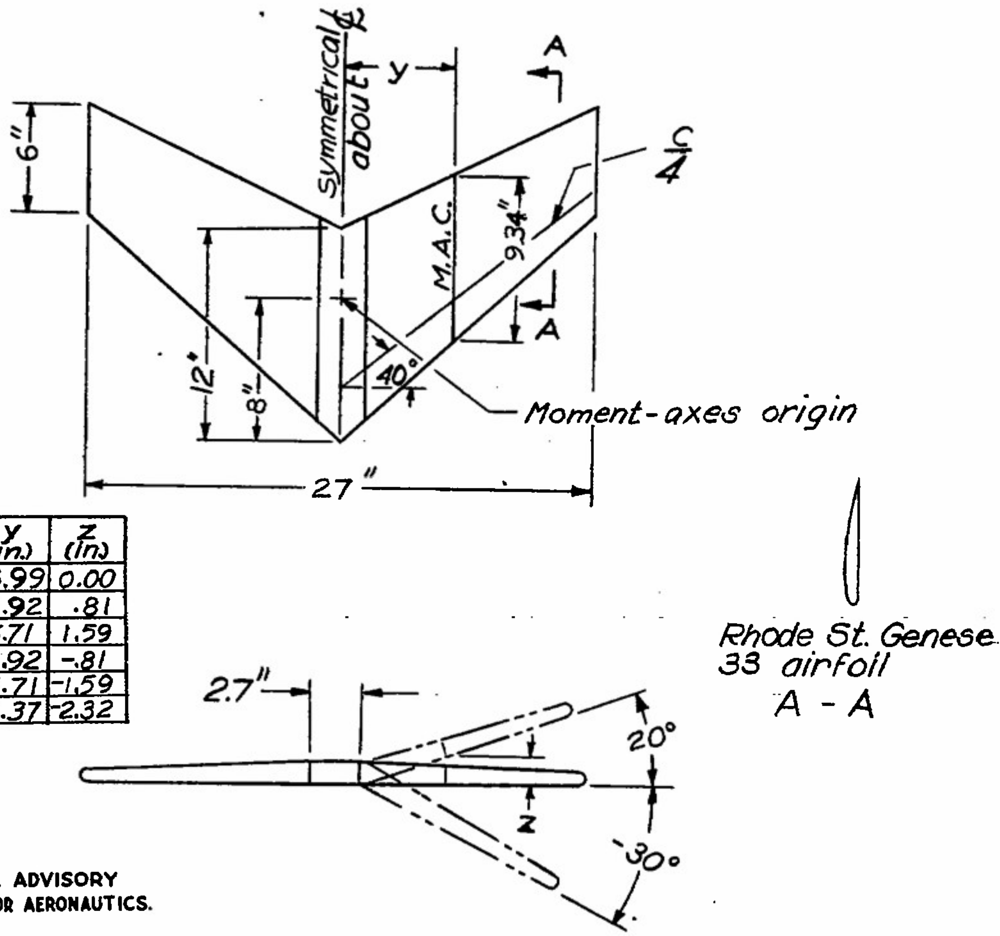


Figure 1.- The stability system of axes; arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.



Dihedral angle	y (in.)	z (in.)
0	5.99	0.00
10	5.92	.81
20	5.71	1.59
-10	5.92	-.81
-20	5.71	-1.59
-30	5.37	-2.32

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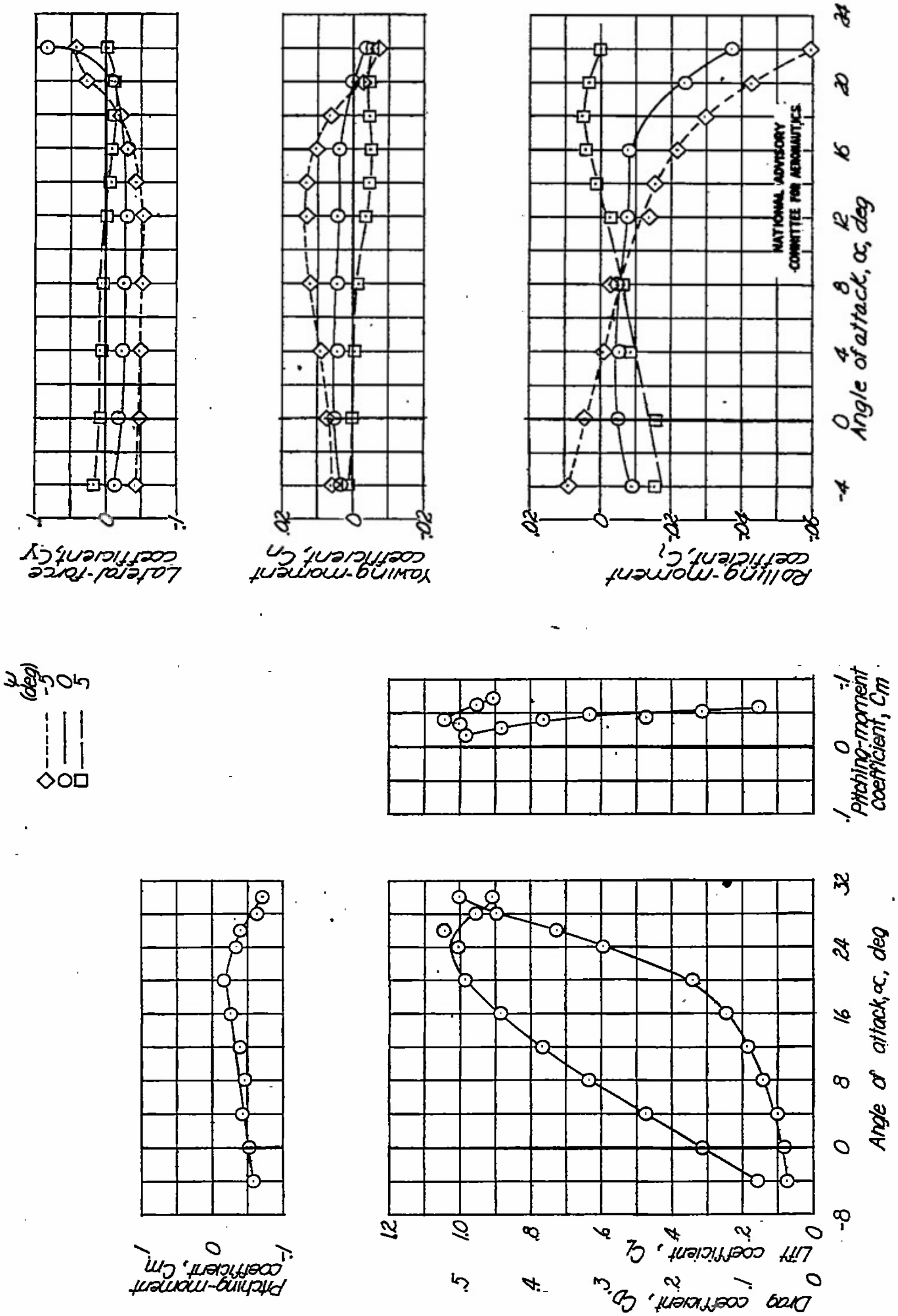
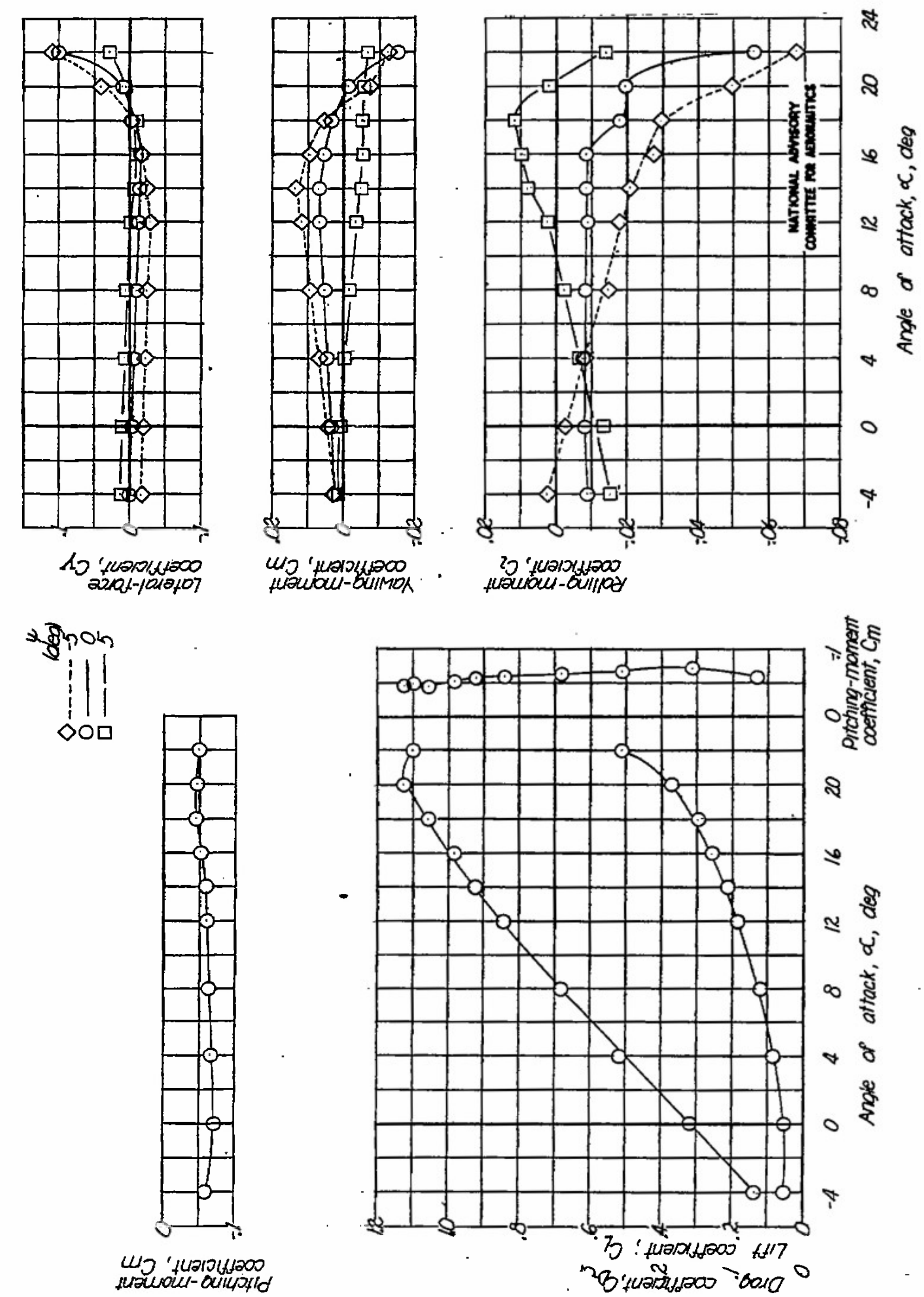
Figure 2.- Drawing of the 40° swept-back wing tested.
Aspect ratio, 3; taper ratio, 0.5.

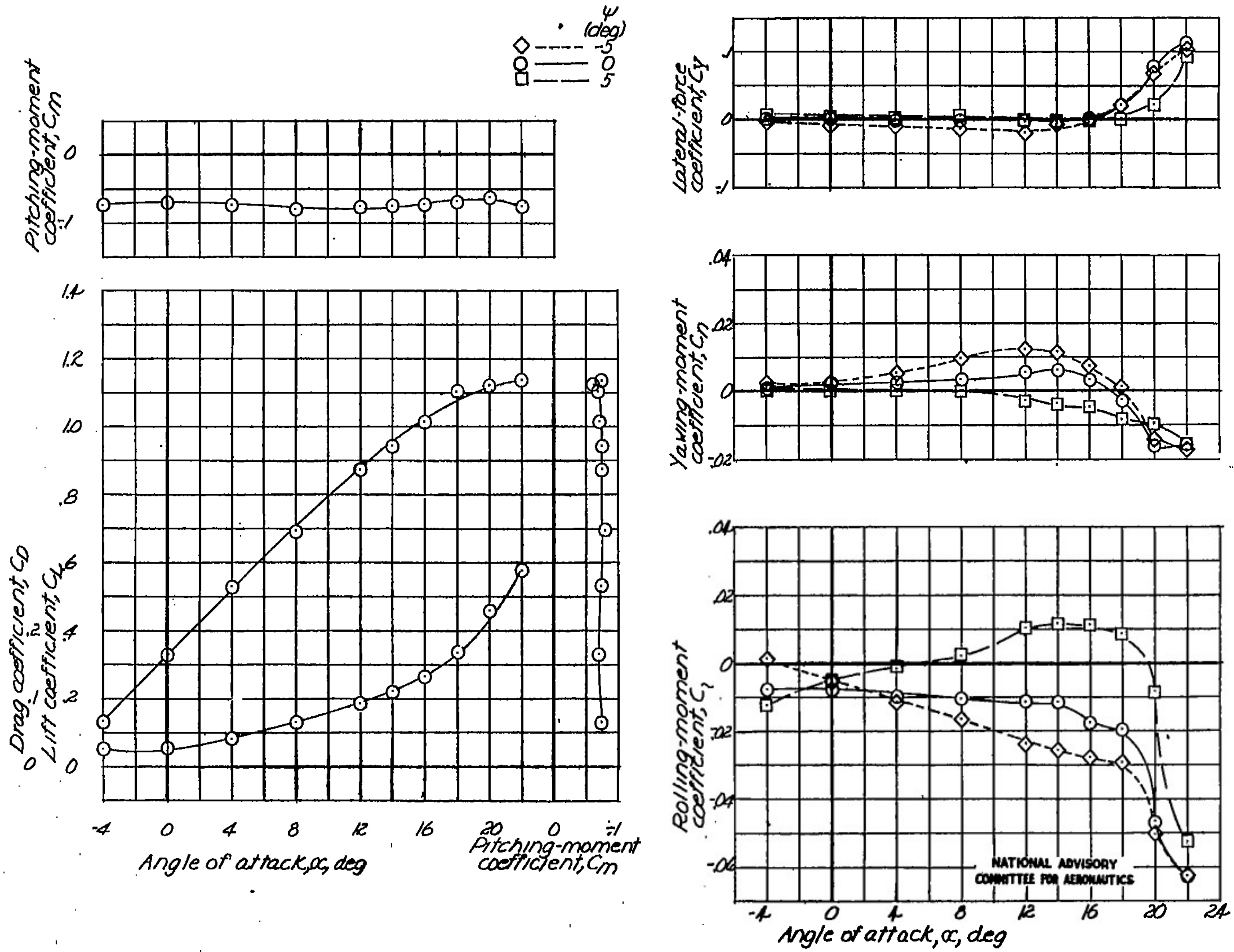


(a) $\Gamma = -30°$.

Figure 3.- Aerodynamic characteristics of a 40° swept-back wing of aspect ratio 3.

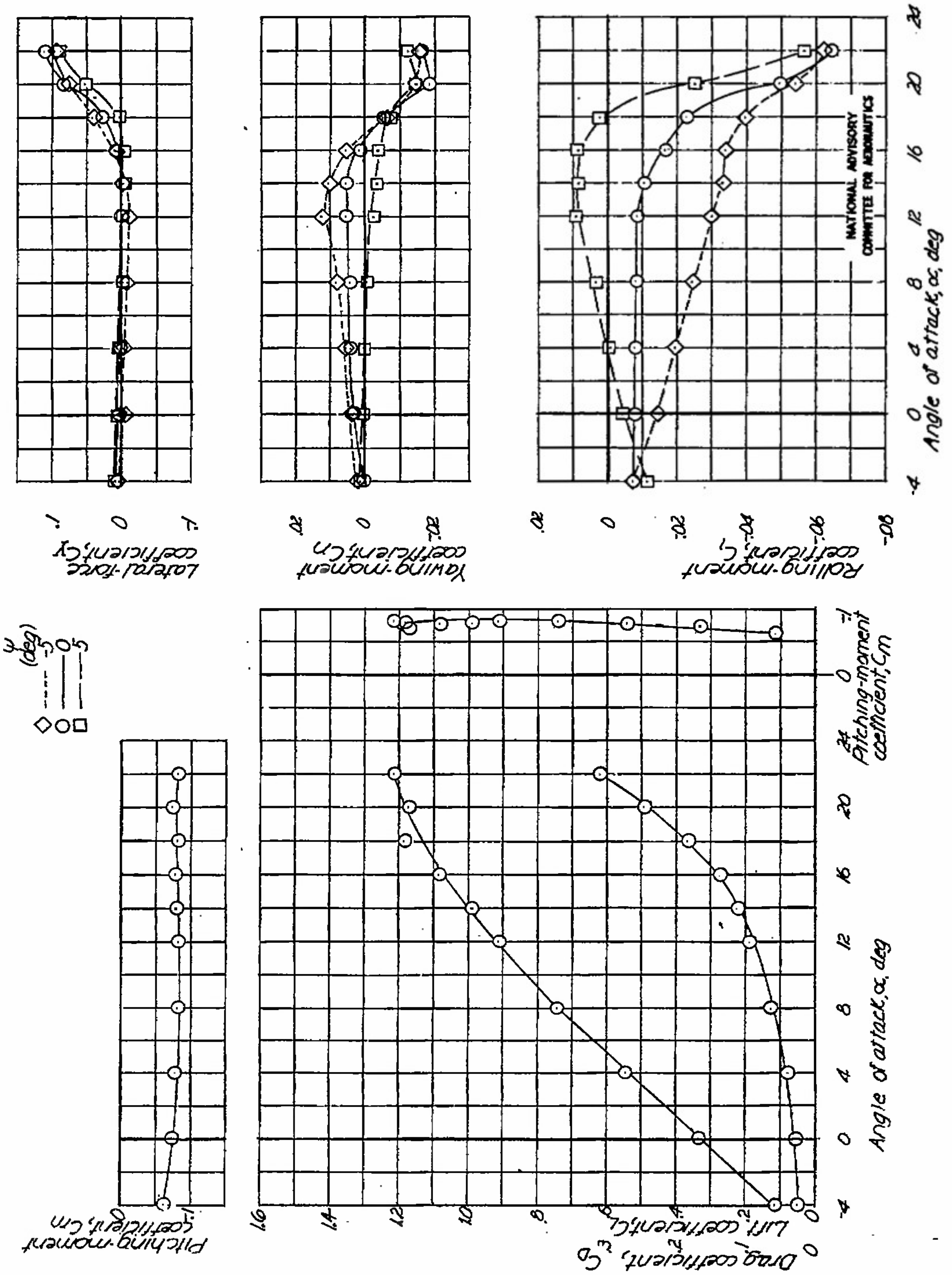


(b) $\Gamma = -20°$.
Figure 3.- Continued.



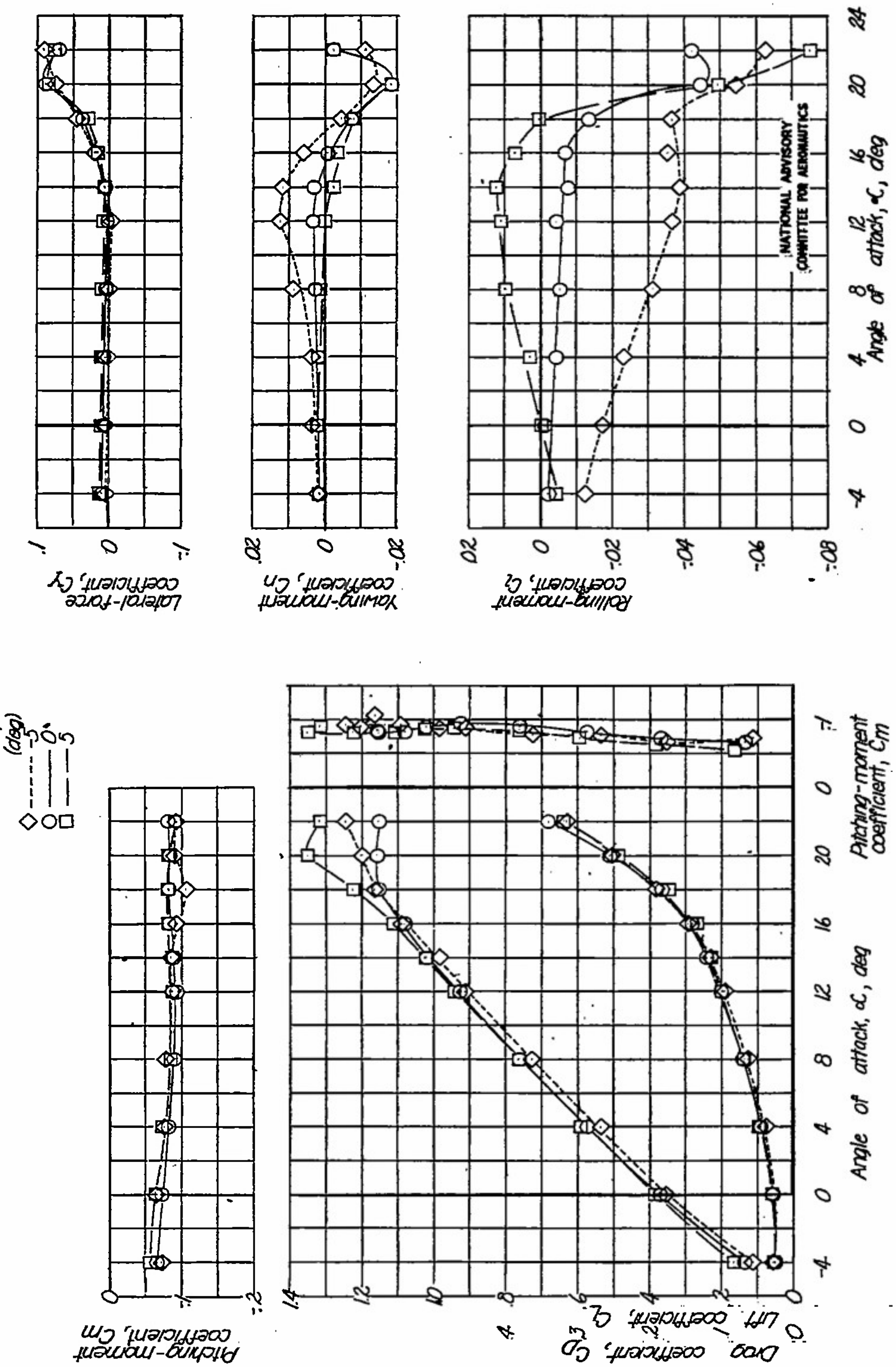
(c) $\Gamma = -10°$.

Figure 3.- Continued.



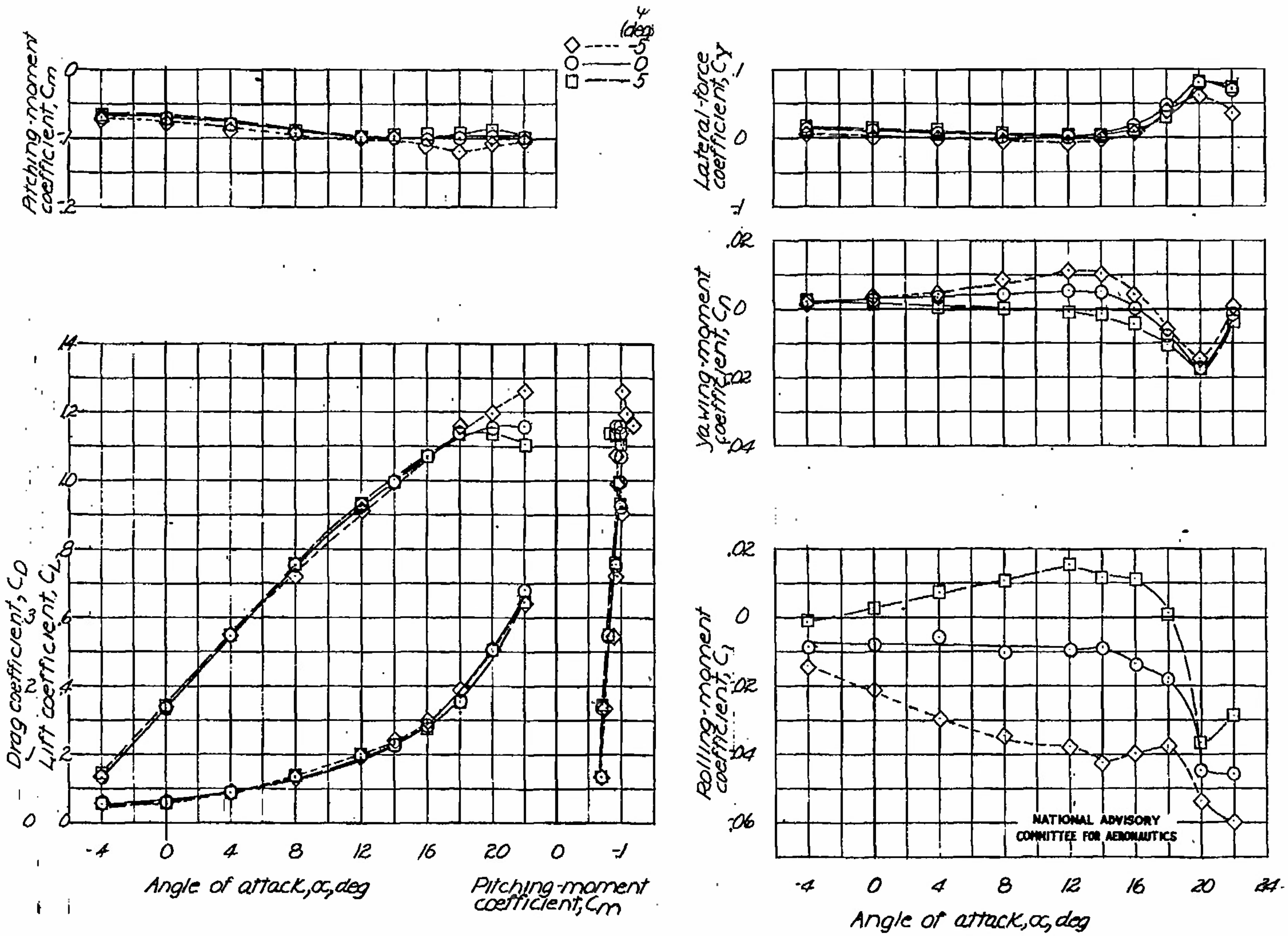
(d) Γ = -5°.

Figure 3.- Continued.



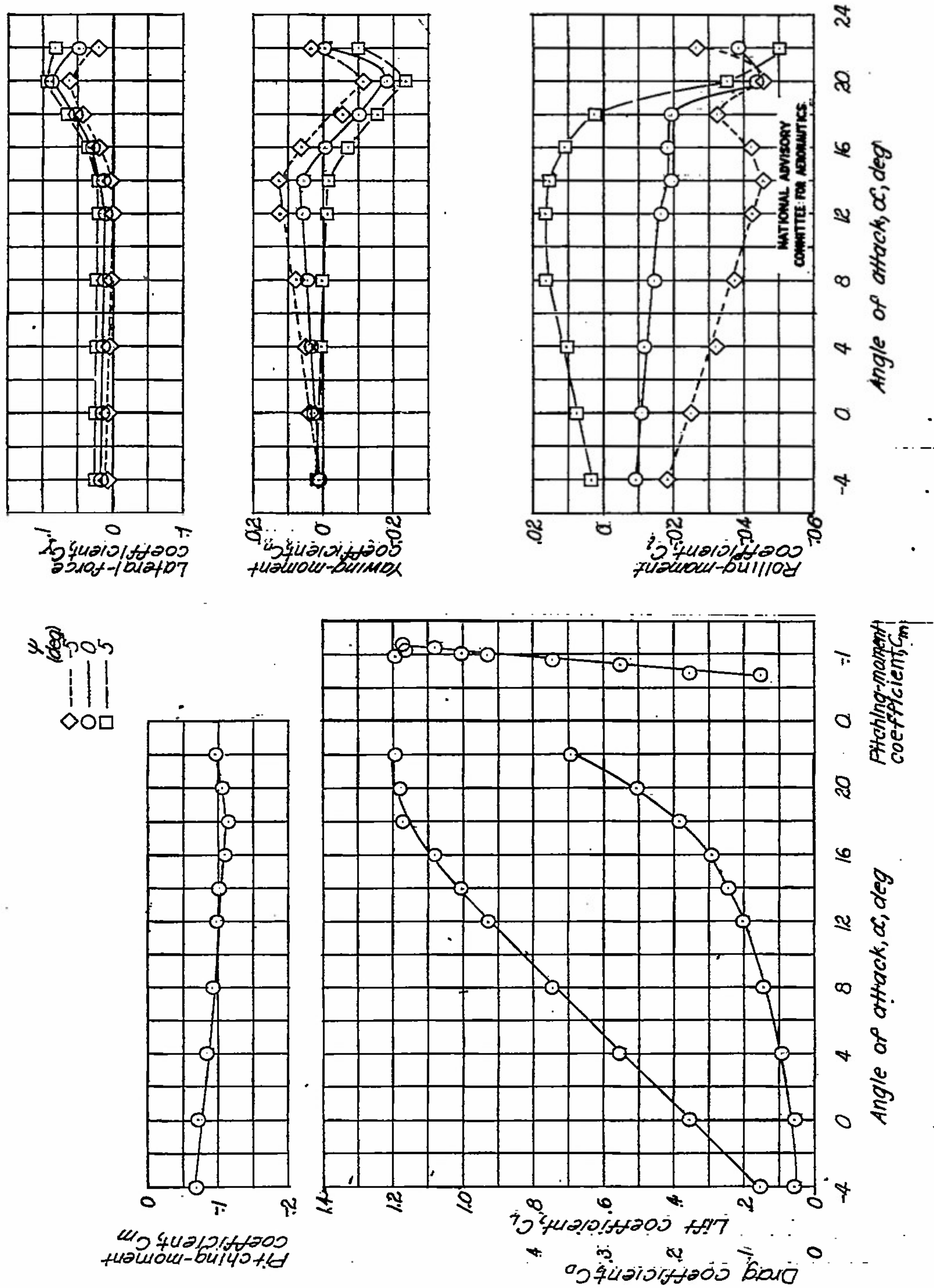
(e) $\Gamma = 0°$.

Figure 3. - Continued.



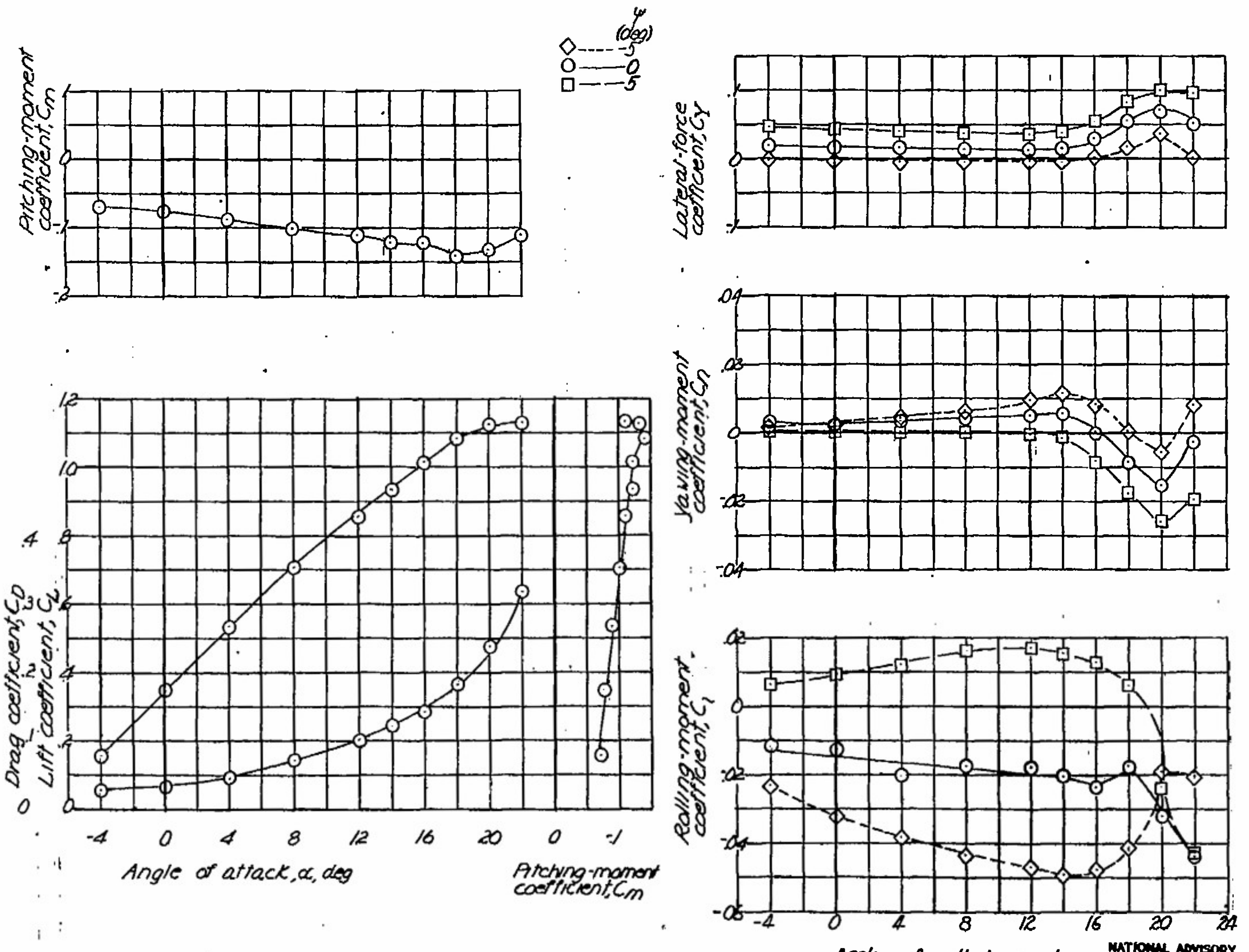
(f) Γ = 5°.

Figure 3.- Continued.



(g) Γ = 10°.

Figure 3.- Continued.



(h) Γ = 20°.

Figure 3 - Concluded.

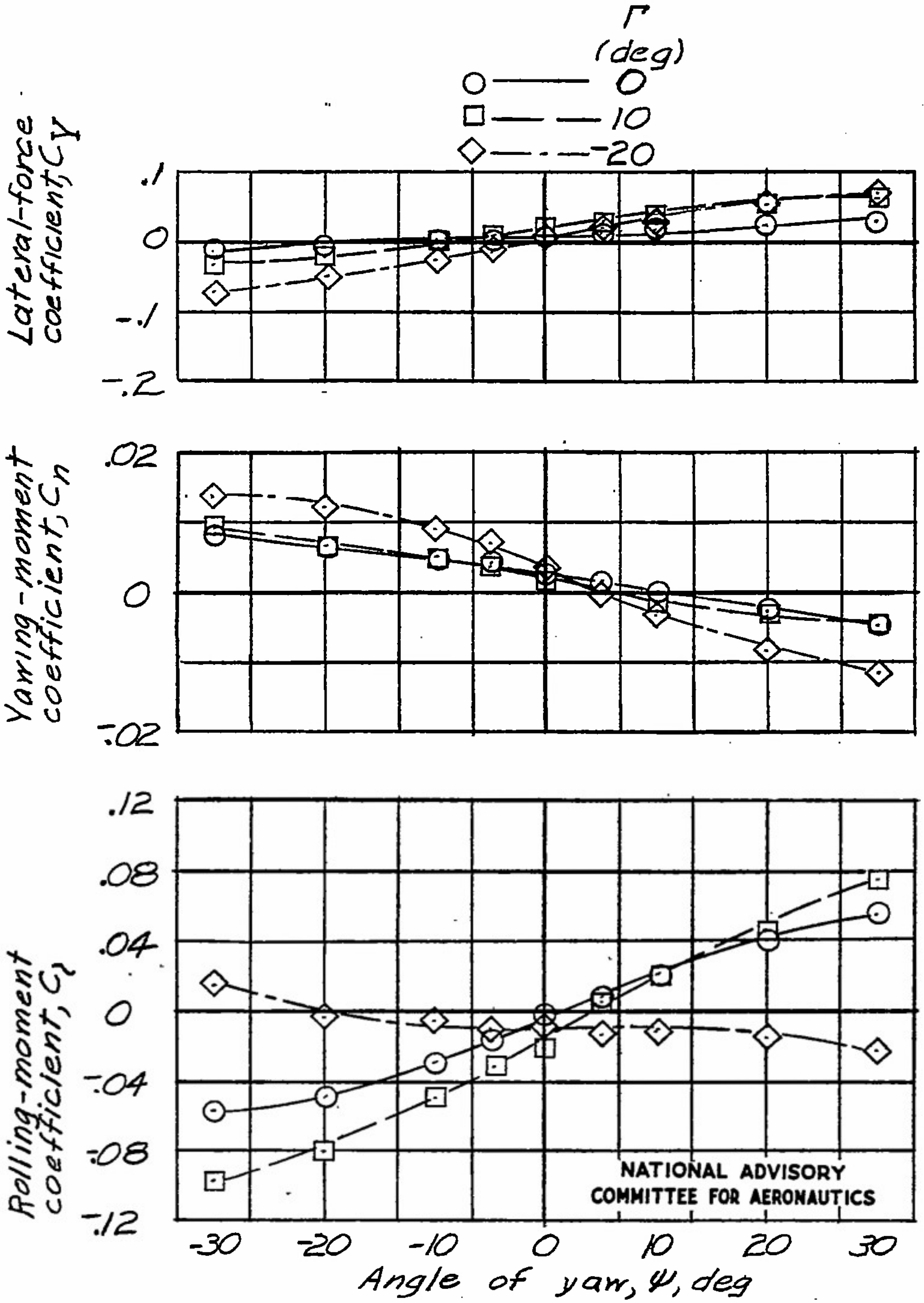


Figure 4.- Variation of lateral-stability parameters with angle of yaw for a 40° swept-back wing of aspect ratio 3. $\alpha = 2^{\circ}$.

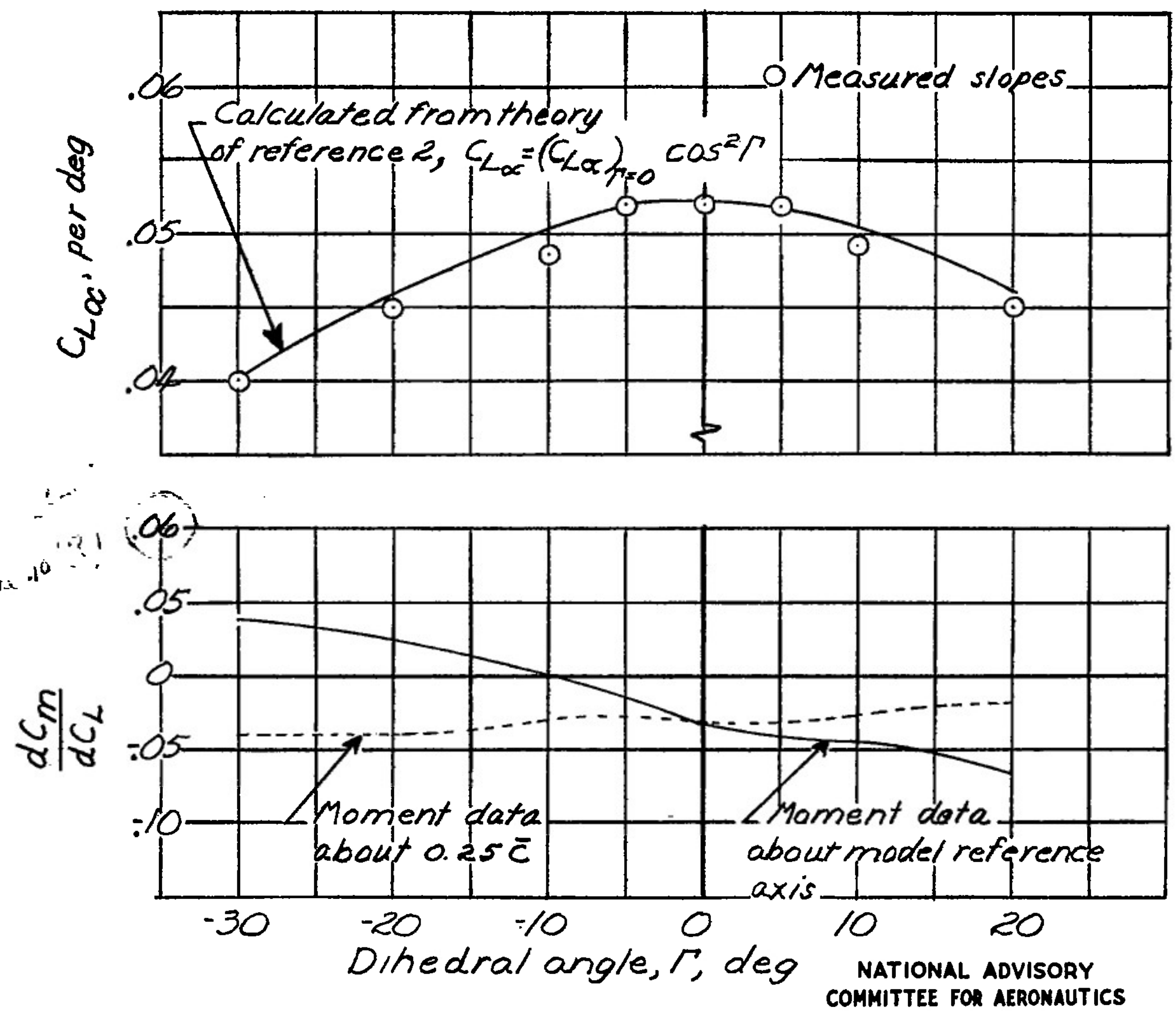


Figure 5.- Variation of lift-curve slope C_{L_α} and longitudinal stability (dC_m/dC_L) with dihedral angle for a 40° swept-back wing of aspect ratio 3.

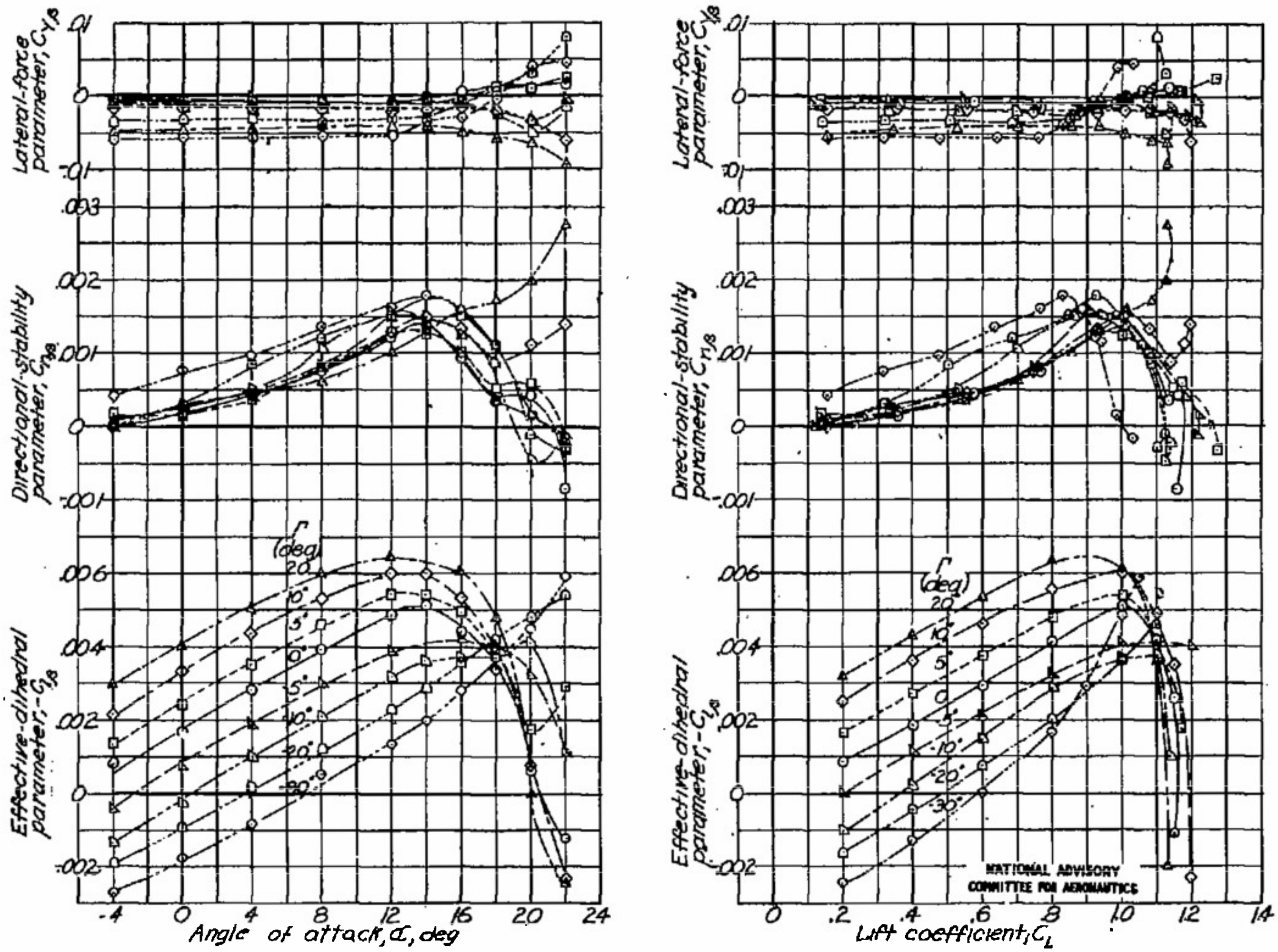


Figure 6.- Effect of angle of attack and lift coefficient on the lateral-stability parameters C_{Y_β}, C_{n_β}, and C_{l_β} for a 40° swept-back wing of aspect ratio 3 at various dihedral angles.

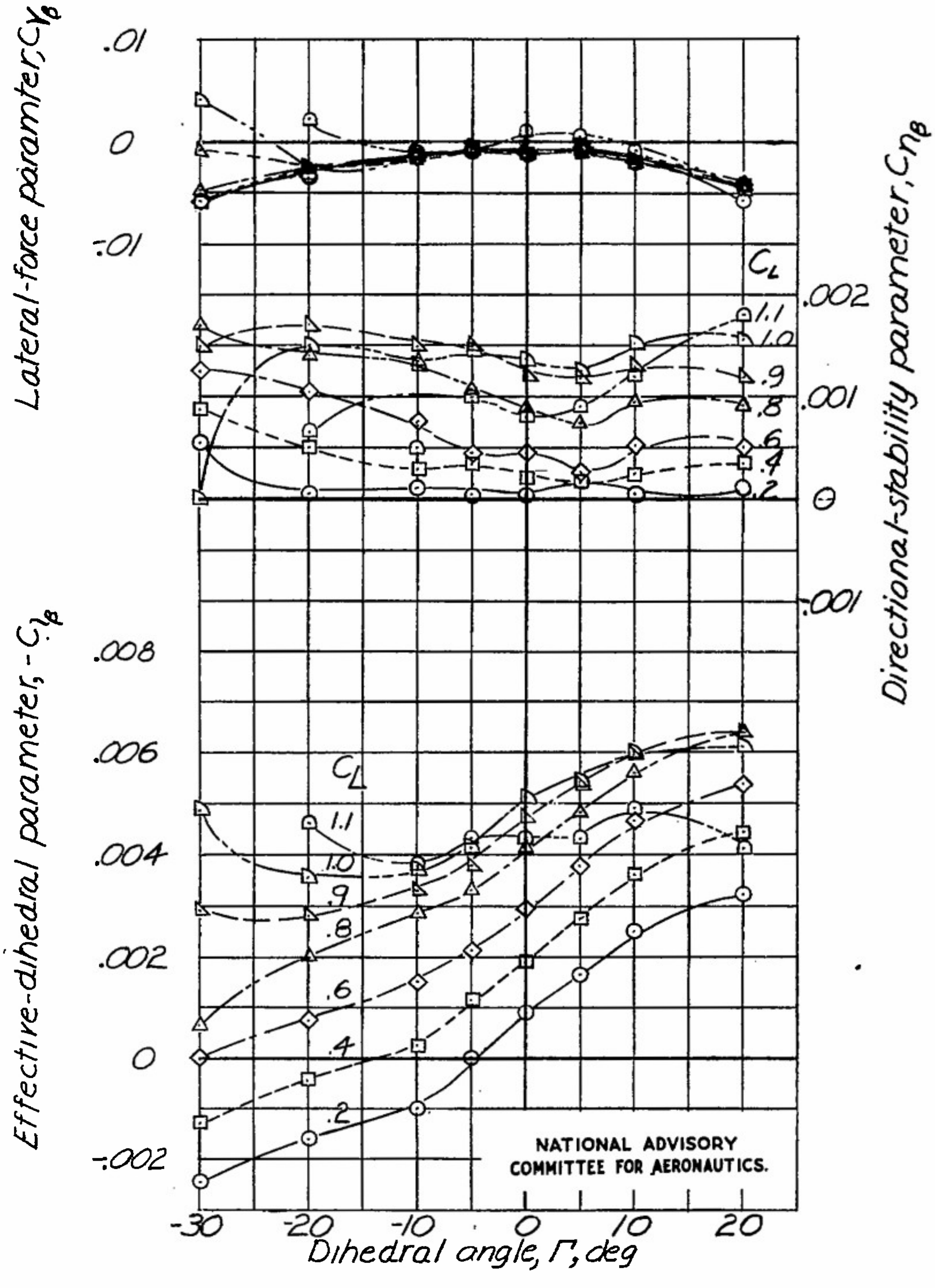


Figure 7.- Effect of dihedral angle on the lateral-stability parameters C_{Y_β}, C_{n_β}, and $-C_{l_\beta}$ of a 40° swept-back wing of aspect ratio 3.

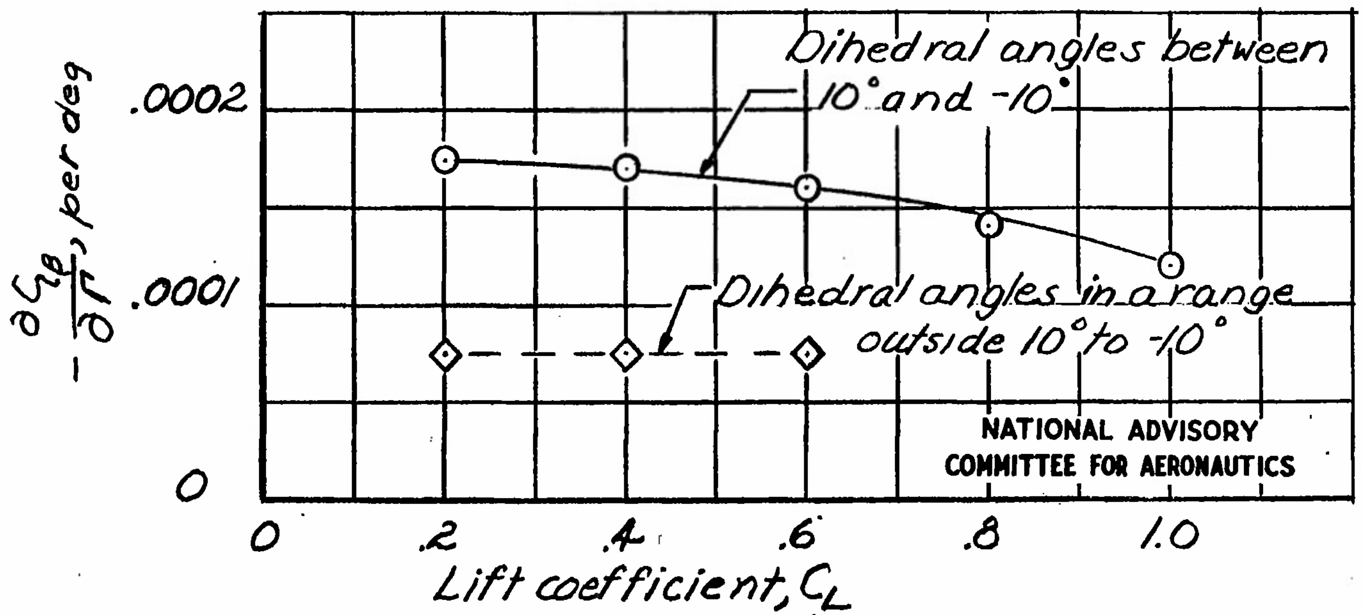


Figure 8.- Variation of $\frac{\partial C_{l_\beta}}{\partial \Gamma}$ with lift coefficient for a 40° swept-back wing of aspect ratio 3.

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